Environmental Research 166 (2018) 384–393

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Cold-related mortality vs heat-related mortality in a changing climate: A case study in Vilnius (Lithuania)

Gerardo Sanchez Martinez[a,*], Julio Diaz[b], Hans Hooyberghs[c], Dirk Lauwaet[c], Koen De Ridder[c], Cristina Linares[b], Rocio Carmona[b], Cristina Ortiz[b], Vladimir Kendrovski[d], Dovile Adamonyte[e]

[a] The UNEP-DTU Partnership, United Nations City, Marmorvej 41, Copenhagen, Denmark
[b] National School of Public Health, Carlos III Institute of Health (ISCIII), Spain
[c] Flemish Institute for Technological Research (VITO), Belgium
[d] WHO European Centre for Environment and Health (World Health Organization Regional Office for Europe), Germany
[e] Centre for Health Education and Diseases Prevention (SMLPC), Lithuania

ARTICLE INFO

Keywords:
Vilnius
Heat-related mortality
Cold-related mortality
Climate change

ABSTRACT

Introduction: Direct health effects of extreme temperatures are a significant environmental health problem in Lithuania, and could worsen further under climate change. This paper attempts to describe the change in environmental temperature conditions that the urban population of Vilnius could experience under climate change, and the effects such change could have on excess heat-related and cold-related mortality in two future periods within the 21st century.

Methods: We modelled the urban climate of Vilnius for the summer and winter seasons during a sample period (2009–2015) and projected summertime and wintertime daily temperatures for two prospective periods, one in the near (2030–2045) and one in the far future (2085–2100), under the Representative Concentration Pathway (RCP) 8.5. We then analysed the historical relationship between temperature and mortality for the period 2009–2015, and estimated the projected mortality in the near future and far future periods under a changing climate and population, assuming alternatively no acclimatisation and acclimatisation to heat and cold based on a constant-percentile threshold temperature.

Results: During the sample period 2009–2015 in summertime we observed an increase in daily mortality from a maximum daily temperature of 30 °C (the 96th percentile of the series), with an average of around 7 deaths per year. Under a no acclimatisation scenario, annual average heat-related mortality would rise to 24 deaths/year (95% CI: 8.4–38.4) in the near future and to 46 deaths/year (95% CI: 16.4–74.4) in the far future. Under a heat acclimatisation scenario, mortality would not increase significantly in the near or in the far future. Regarding wintertime cold-related mortality in the sample period 2009–2015, we observed increased mortality on days on which the minimum daily temperature fell below − 12 °C (the 7th percentile of the series), with an average of around 10 deaths a year. Keeping the threshold temperature constant, annual average cold-related mortality would decrease markedly in the near future, to 5 deaths/year (95% CI: 0.8–7.9) and even more in the far future, down to 0.44 deaths/year (95% C: 0.1–0.8). Assuming a "middle ground" between the acclimatisation and non-acclimatisation scenarios, the decrease in cold-related mortality will not compensate the increase in heat-related mortality.

Conclusion: Thermal extremes, both heat and cold, constitute a serious public health threat in Vilnius, and in a changing climate the decrease in mortality attributable to cold will not compensate for the increase in mortality

Abbreviations: AD, attributable deaths; *AF*, attributable fraction; *ARIMA*, autoregressive integrated moving average; *CI*, confidence interval; *CMIP5*, Coupled Model Intercomparison Project 5; DTU, Technical University of Denmark; *GCMs*, global climate models; *ICD*, International Classification of Diseases; *IHD*, ischemic heart disease; *IPCC*, Intergovernmental Panel on Climate Change; ISCIII, Institute of Health Carlos III; *PAF*, Population Attributable Fraction; PM_{10}, particulate matter less than 10 μm in diameter; $PM_{2.5}$, particulate matter less than 2.5 μm in diameter; *RAMSES*, Reconciling Adaptation, Mitigation and Sustainable Development for Cities; *RCP8.5*, Representative Concentration Pathway scenario 8.5; *RR*, relative risks; SMLPC, Centre for Health Education and Diseases Prevention; *VITO*, Flemish Institute for Technological Research; *WHO*, World Health Organization; *WPP*, World Population Prospects

* Corresponding author.
E-mail addresses: gsama@dtu.dk (G.S. Martinez), j.diaz@isciii.es (J. Diaz), hans.hooyberghs@vito.be (H. Hooyberghs), dirk.lauwaet@vito.be (D. Lauwaet), koen.deridder@vito.be (K. De Ridder), clinares@isciii.es (C. Linares), rocio.carmona@isciii.es (R. Carmona), cortizb@isciii.es (C. Ortiz), kendrovskiv@who.int (V. Kendrovski), dovile.adamonyte@smlpc.lt (D. Adamonyte).

https://doi.org/10.1016/j.envres.2018.06.001
Received 23 March 2018; Received in revised form 23 May 2018; Accepted 1 June 2018
Available online 21 June 2018
0013-9351/ © 2018 Elsevier Inc. All rights reserved.

attributable to heat. Study results reinforce the notion that public health prevention against thermal extremes should be designed as a dynamic, adaptive process from the inception.

1. Background

Fewer studies focus on cold-related mortality than on heat-related mortality. Probable reasons include a longer delay between exposure to cold and effect (Alberdi et al., 1998; Anderson and Bell, 2009; Díaz et al., 2005) as well as an overlap in time of concomitant infectious diseases (Carmona et al., 2016; Rocklov et al., 2014; Ryti et al., 2016). In addition, while heat waves are increasing in frequency, duration and intensity, cold spells are decreasing. This trend is likely to continue (IPCC, 2013; Melillo, 2014), despite some evidence suggesting a prospective increase in cold waves in medium latitudes (Cohen et al., 2014; Zhang et al., 2016). However, a reduction in the frequency, duration or intensity of cold waves may not necessarily translate into a decrease in cold-related mortality. Various studies in multiple locations suggest that while heat-related mortality is in decline due to various adaptative processes (Gasparrini et al., 2015; Miron et al., 2015; Díaz et al., 2015a; Ha and Kim, 2013; Petkova et al., 2014), cold-related mortality has either remained constant or increased (Gasparrini et al., 2015; Díaz et al., 2015a; Linares et al., 2016).

Consistently, studies on future impacts of thermal extremes on health focus mostly on heat and its effects on mortality. Most researchers assume that neither the “heat wave” threshold temperature nor the effect of temperature increase itself will change in time, so projections of mortality attributable to heat in far future horizons tend to be quite high (Peng et al., 2011; Wu et al., 2014; Martinez et al., 2016; Roldán et al., 2016). Others, however, assume a heat acclimatisation process (Martinez et al., 2018). Very few studies analyse projected impacts of cold, and all assume no changes in the impacts of cold on mortality across time (Wang et al., 2016).

The evidence base on health and temperature extremes (particularly heat, as mentioned) is relatively well established in several European countries. However, research in this field is still scarce in Baltic countries. In the context of the technical assistance of the WHO Regional Office for Europe to its Member States in the area of climate change and health, we set out to contribute to addressing this gap in Lithuania, where various studies suggest a significant impact of thermal extremes on health and wellbeing (Liukaitytė, 2011; Styra et al., 2009; Vaičiulis and Radišauskas, 2014). However, no study had comprehensively analysed the impacts of heat and cold on mortality in urban settings in the country.

This study has various objectives: first, to analyse retrospectively the impact of heat and cold on daily short-term mortality in Vilnius, determining threshold temperatures for both. Second, to estimate the projected impact of heat and cold in a near future period (2030–2045) and a far future one (2085–2100), under Representative Concentration Pathway (RCP) 8.5. For the projected impacts, we considered two hypotheses: 1) constant thresholds for heat waves and cold waves, and 2) thresholds for heat waves and cold waves varying over time. In addition, we compare projected heat and cold impacts, to determine whether lower cold-related mortality (Kinney et al., 2015; Staddon et al., 2014) will compensate an increase in heat-related deaths.

The results of this study show the change in environmental temperature conditions that the urban population of Vilnius could experience under climate change, and the effects such change could have on excess heat-related and cold-related mortality in two future periods within the 21st century. These results can inform both current-day prevention efforts and relevant urban health adaptation policies.

2. Methods

2.1. Retrospective study of the impact of thermal extremes on short-term daily mortality

2.1.1. Data sources

2.1.1.1. Environmental variables.

- Air temperature data**:** Air temperature measurements for the years 2009–2015 were obtained from the Lithuanian Hydrometeorological Services under the Ministry of Environment. Only daytime temperatures with a 3 h frequency were made available for the current study. Measurements took place daily at 9 h, 12 h, 15 h and 18 h. We have used the measurement at 9 h as a proxy for the minimum daily temperature, and the measurement at 12 h as proxy for the maximum daily temperature.
- Relative humidity**:** Data were also available on relative humidity (rH) at 9 h, 12 h, 15 h and 18 h for the same period; we worked with mean relative humidity obtained as the average of the relative humidity readings recorded at the above-mentioned times of day.
- Chemical air pollution: daily data were available on μg/m^3 of $PM_{2.5}$, PM_{10}, SO_2, NO_2 and O_3 for the same period, recorded at four monitoring stations, and received from the Environmental Protection Agency in Lithuania. We worked with the daily means obtained based on the values furnished by these four stations.

2.1.1.2. Health variables. We calculated the daily crude mortality rate of Vilnius based on the following two variables:

1. Daily mortality: The geographical area under study comprises the Municipality of Vilnius, for which we collected from the Institute of Hygiene the daily mortality series corresponding to the period 01-01-2009 to 31-12-2015 for all-cause mortality (International Classification of Diseases, 10th Revision (ICD-10:A00-R99).
2. Population: Population data for the city of Vilnius were obtained from Statistical Office of Lithuania (DoS, 2018) for the period 2009–2015.

2.1.2. Statistical methodology

2.1.2.1. Determination of cold wave and heat wave threshold temperatures. Some definitions of heat wave or cold wave require that the threshold temperature is exceeded two or more days for the series to qualify as either (Guo et al., 2017). However, from the health impact standpoint, mortality increases can be observed already when the threshold value is exceeded only by a single day, an observation confirmed in several studies analyzing the impact of heat and cold on mortality (Díaz et al., 2002; Montero et al., 2012; Miron et al., 2015, Díaz et al., 2015b; Carmona et al., 2016; Martinez et al., 2018; Gasparrini et al., 2017; Wang et al., 2016). However, acknowledging that there is no consensus on what constitutes a heat wave or a cold wave, we considered impacts in this study on the basis of an operational definition, following previous studies (see for instance Martinez et al., 2018). Thus, we defined “hot days” as days with mortality attributable to heat, and "cold days" as days with mortality attributable to cold.

The extent of the retrospective analysis was limited by the availability of daily mortality data, corresponding to the period 2009–2015, hereon referred to as the “sample period”. Impact of heat was studied for summertime (June-September) and impact of cold for wintertime (November-March). In both cases, we aimed at determining a threshold temperature. For heat, it was defined as the maximum daily

temperature beyond which mortality significantly increases (Tmax-threshold) (Díaz et al., 2002, 2015b). For cold, it was defined as the minimum daily temperature below which mortality increases significantly (Tmin-threshold) (Carmona et al., 2016). These threshold temperatures were ascertained from the scatterplot diagrams of pre-cleaned mortality rate time series (Box et al., 1994) against the corresponding temperature series. In these diagrams, Tmax-threshold and Tmin-threshold are associated to the corresponding temperature in the daily Tmax series for summertime and the daily Tmin series for wintertime, respectively. A "hot day" (i.e. a day in which heat-related mortality occurs) is then based on the value of Tmax-threshold through a newly created variable thusly defined (Díaz et al., 2006, 2015b; Carmona et al., 2016; Martinez et al., 2018):

$$T_{heat} = 0 \quad si\ T_{max} < T_{max-threshold}$$

$$T_{heat} = T_{max} - T_{max-threshold} \quad si\ T_{max} > T_{max-threshold}$$

Since the effect of heat on mortality may not be immediate, the following lagged variables will also be calculated: T_{heat1} (lag 1), which accounts for the effect of the temperature of a day "d" on the mortality the next day "d + 1"; T_{heat2} (lag 2), which accounts for the effect of the temperature of a day "d" on the mortality two days later "d + 2"; and so on. The number of lags is based on the existing literature, which shows that heat effects happen mostly in the short term (Theat: lags 1–4) (Alberdi et al., 1998).

Similarly, we shall define the occurrence of a "cold day" (i.e. a day in which cold-related mortality occurs) when:

$$T_{cold} = T_{min-threshold} - T_{min} \quad si\ T_{min} < T_{min-threshold}$$

$$T_{cold} = 0 \quad si\ T_{min} > T_{min-threshold}$$

The effect of cold on mortality is not immediate either, so for this exposure we also defined lagged variables. The existing literature shows that cold has effects both in the short and the medium term (T_{cold}: lags 1–13) (Alberdi et al., 1998).

2.1.2.2. Calculation of the impact of "hot days" and "cold days" on daily mortality. To determine the values of the Relative Risks (RR) attributable to hot days and cold days respectively, we used a Generalized Linear Models (GLM) methodology linked with a Poisson regression. We ascertained the significant variables in the model to calculate the RRs through a "Stepwise backward" methodology. This method starts with an initial model including all explanatory variables, and gradually eliminates those that are individually least statistically significant. The process is repeated until all remaining variables are significant at $p < 0.05$. We went through this process for all wintertime (November through March) and summertime (June through September) periods.

We used generalized linear models with the Poisson regression to calculate the coefficients that allow determining the value of the RR. The following covariables were included in the analysis, in order to control for the trend and seasonalities of the series, as well as the lags in the T_{heat} and T_{cold} mentioned before:

- Sine and Cosine functions of 365, 180 and 120 days to account for annual, six-monthly and four month periodicities.
- The trend of the series, using a counter (n1), equal to 1 for the first day of the series, 2 for the second day, and so on, successively.
- Autoregressive character of the series by introducing a first order autoregressive process (AR1).
- The modelling process was carried out in reverse order manually, eliminating the variables in a stepwise procedure until $P < 0.05$

The explanatory variables include not only the effect of the previously defined T_{heat} and T_{cold}, but also that of other environmental variables known to act synergistically with temperature in aggravating mortality. In terms of meteorological variables, for instance, the role of relative humidity (RH) has been studied during hot days and cold days (Díaz et al., 2015b; Carmona et al., 2016), and we have considered it in this study too. The RH variable was established as linearly related to mortality and its effect considered until lag 14 (Alberdi et al., 1998; Díaz et al., 2015b). Similarly, multicentre and cross-over studies have shown the synergistic effect of high temperatures on inhalable particles (Stafoggia et al., 2008; Stieb et al., 2009), as well as on ozone (Zmirou et al., 1998; Díaz et al., 2002). Strong interactions have also been reported between chemical air pollution and low temperature, so the available chemical air pollution data were also introduced in the model as control variables. Methodologically, based on previous studies (Linares et al., 2006; Jiménez et al., 2009), the relationship between PM_{10}, $PM_{2,5}$, $NO_2$and SO_2 and mortality is assumed to be linear, with an effect until lag 4. Therefore, we created the corresponding lagged variables in the same way as we did for temperature. For Ozone, we included until lag 8 (Díaz et al., 1999).

We calculated the increases in RR corresponding to the unit increases of each independent variable:

- T_{heat}: increase for each 1^0C increase beyond the established threshold temperature (Tmax-threshold)
- T_{cold}: increase for each 1^0C decrease below the established threshold temperature (Tmin-threshold)
- Chemical air pollution: increase for each increase of 10 μg/m^3 in measured daily concentration of every pollutant
- Relative humidity: increase for each 1% increase in relative humidity

Based on the RR we calculated the Population Attributable Fraction (PAF) associated to those increases, through the following equation:

$$PAF = (RR - 1/RR.)*100$$

2.1.2.3. Heat and Cold Attributable deaths during the sample period (2009–2015). To calculate attributable mortality, we used the methodology of a previous study (Martinez et al., 2018). First, we calculated the excess or deficit in temperature beyond (heat) or below (cold) the daily threshold temperature with the following equation:

$$\text{Excess°C during hot day} = \Sigma \text{Tmax–Tmax} - \text{threshold}$$

$$\text{Deficit °C during cold day} = \Sigma\ \text{Tmin} - \text{threshold–Tmin.}$$

The Σ extends to all days in which daily maximum temperature goes beyond the hot day temperature threshold and those were daily minimum temperature goes below the cold day temperature threshold. Since we have calculated the % increase in mortality per ˚C through the AR, the total percentage of mortality for the whole excess of degrees for the sample period (2009–2015) is:

$$\%\text{mortality attributable to heat} = \text{AR x Excess°C}$$

We can then calculate the daily mortality by also taking into account the average daily mortality in Vilnius during hot days:

$$\text{Mortality attributable to heat} = (\%\ \text{mortality attributable to hot days x average mortality})/100$$

$$\text{Daily mortality attributable to heat} = \text{mortality attributable to hot days} / \text{number of hot days}$$

For the case of cold, the procedure was similarly applied to ˚C below the threshold temperature

2.2. Prospective climate assessment

2.2.1. Data sources

To calculate the impact of thermal extremes in future years, we

compiled time series of projected temperatures using a statistical method. The methodology relies on two steps:

- In a first step, we compose monthly rescaling functions describing the change of the percentiles of the daily minimum and maximum temperatures in the GCM-output. For instance, for each month, we determine how the 75th percentile of the daily minimal temperature changes between the current-day (2000 – 2015) and the future periods (2030–2045 and 2085–2100). This analysis is based on the output of a representative set of GCMs contained in the archives of the Coupled Model Intercomparison Project (CMIP5) of the Intergovernmental Panel on Climate Change (IPCC) (Ryti et al., 2016).
- In a second step, the rescaling functions are applied on the Vilnius measurements to compose yearlong daily minimum and maximum temperatures for the two periods under consideration. In this way, the methodology takes into account both the seasonal pattern of climate change, and the increase in the frequency and severity of hot days. The methodology has been used for the Representative Concentration Pathway 8.5 (RCP8.5), representing a weak mitigation strategy (Ryti et al., 2016).

Population projections for the periods 2030–2045 and 2085–2100 were based on the United Nations World Population Prospects (WPP) forecasts for Lithuania, "Medium Variant" (UNDESA, 2008, 2013). Vilnius is the largest city in the country in terms of population. In the late 2000s, Vilnius saw years of declines in its population, dropping from its peak 559,234 in 2009 to 534,348 in 2011. However, since 2011, the city has seen population increases of less than 1%, indicating that the city may continue to see slow growth in the years ahead (DoS, 2018). Taking as reference the population data for the Vilnius agglomeration in the year 2015, we calculated the proportion it represented from the total national population. Thereafter, that proportion was assumed constant, whereby the population of Vilnius would behave like that of Lithuania as a whole.

2.2.2. Statistical methodology

2.2.2.1. Heat- and Cold-related mortality for 2030–2045 and 2085–2100. To calculate the impact of cold days and hot days on mortality under the projected scenarios, we considered two hypotheses:

Hypothesis 1. the threshold temperature of hot days and cold days does not change over time. That is, there is no acclimatisation to either heat or cold.

Hypothesis 2. there is a process or acclimatisation to both heat and cold whereby the threshold temperature changes, but the percentile corresponding to that threshold in the baseline series remains constant.

In both cases, we assumed that AR remains constant and equal to the one calculated for the sample period 2009–2015

3. Results

3.1. Heat- and Cold–mortality relationship during the sample period: 2009–2015

The descriptive statistics of the independent and dependent variables are shown in Table 1.

3.1.1. Determination of cold day and hot day threshold temperatures

Fig. 1 shows the relevant scatterplot diagrams. The Y-axis represents the pre-cleaned mortality series, and the X-axis the maximum (1a) and minimum (1b) daily temperatures. In the case of hot days, heat-related mortality begins to rise statistically significantly from a maximum daily temperature of 30^{0}C upwards (Fig. 1a), a threshold which coincides with the 96th percentile of the maximum daily temperature series for the summer months (June to September) across the period considered. We therefore consider that a hot day occurs in this context when the daily maximum temperature rises above 30 °C (Tmax-Threshold).

Conversely, cold-related mortality in the sample period starts to statistically significantly increase when minimum daily temperatures drop below − 12 °C (Fig. 1b). This value (Tmin-threshold) coincides with the 7th percentile of the maximum daily temperature series for the winter months (November to March).

3.1.2. Calculation of the impact of heat and cold on daily mortality

Table 2 shows the results of the Poisson model, in which only heat at lag 1 and PM_{10} at lag 0 are associated with summertime mortality. An increase of 1 °C in daily maximum temperature above 30 °C results in an increase in the risk of daily all-cause mortality of 7.1%. The table also shows the impact of cold days during the sample period. The effect of cold is associated with all-cause mortality at lag 1. That is, mortality rises one day after the minimum temperature drops below − 12 °C. Relative humidity is statistically significant at lag 2, and positive, implying that higher relative humidity increases mortality on the two days after the minimum temperature drops below − 12 °C. Among the pollutants, $PM_{2.5}$ is significantly associated at lag 2 and SO_2 at lag 1. Values of daily minimum temperature under − 12 °C translate into an increase in all-cause mortality risk of 1.6%.

3.1.3. Heat and cold attributable deaths during the sample period (2009–2015)

We calculated the mortality attributable to heat and cold during the sample period in Vilnius according to our established methodology. Results are listed in Table 3.

Across the period 2009–2015, there were 29 days on which the maximum daily temperature rose above 30 °C. The aggregate heat-related mortality in this period was 52 persons (95% CI: 19–84), which translates as an annual mortality of 7.4 persons (95% CI: 2.7–12), i.e., for each day on which there is a daily maximum temperature above 30 °C, there is a total heat-related mortality of 1.80 persons (95% CI: 0.63–2.90).

For cold days, across the period 2009–2015, there were 71 days on which the minimum daily temperature fell below − 12 °C. Cold-related mortality in this period totalled 70 persons (95% CI: 13–124) which translates as an annual mortality of 10 persons (95% CI: 1.9 −17.7), i.e., for each day on which there is a daily minimum temperature below − 12 °C, there is a total cold-related mortality of 1 person (95% CI: 0.2–1.7).

3.2. Health impact assessment for 2030–2045 and 2085–2100

3.2.1. Heat –related mortality for 2030–2045 and 2085–2100

Under our first hypothesis, that is, a constant Tmax-threshold (i.e. a maximum daily temperature of 30 °C fixed), there would be 142 "hot days" in Vilnius during the period 2030–2045 under RCP8.5, reaching 8.9 "hot days"/year versus the sample period figure of 4.1 days. Attributable mortality across the 2030–2045 period would be 381

Table 1
Descriptive statistics of the analysed variables, sample period: 2009–2015.

	N	Minimum	Maximum	Mean	Std. Dev.
Total_Mortality	2556	3	30	15.79	4.05
Tmin (°C)	2556	− 24.00	32.30	8.53	10.37
Tmax (°C)	2556	− 19.30	33.80	10.08	10.44
Humidity (%)	2554	22.50	100.00	71.39	18.24
$PM_{2.5}$ (μg/m^3)	2496	1.70	107.03	18.68	11.80
PM_{10} (μg/m^3)	2556	3.70	137.34	25.84	14.14
O_3 (μg/m^3)	2525	1.05	105.45	36.96	16.80
NO_2 (μg/m^3)	2556	3.59	71.93	21.26	8.75
SO_2 (μg/m^3)	2556	0.00	39.17	2.29	2.62

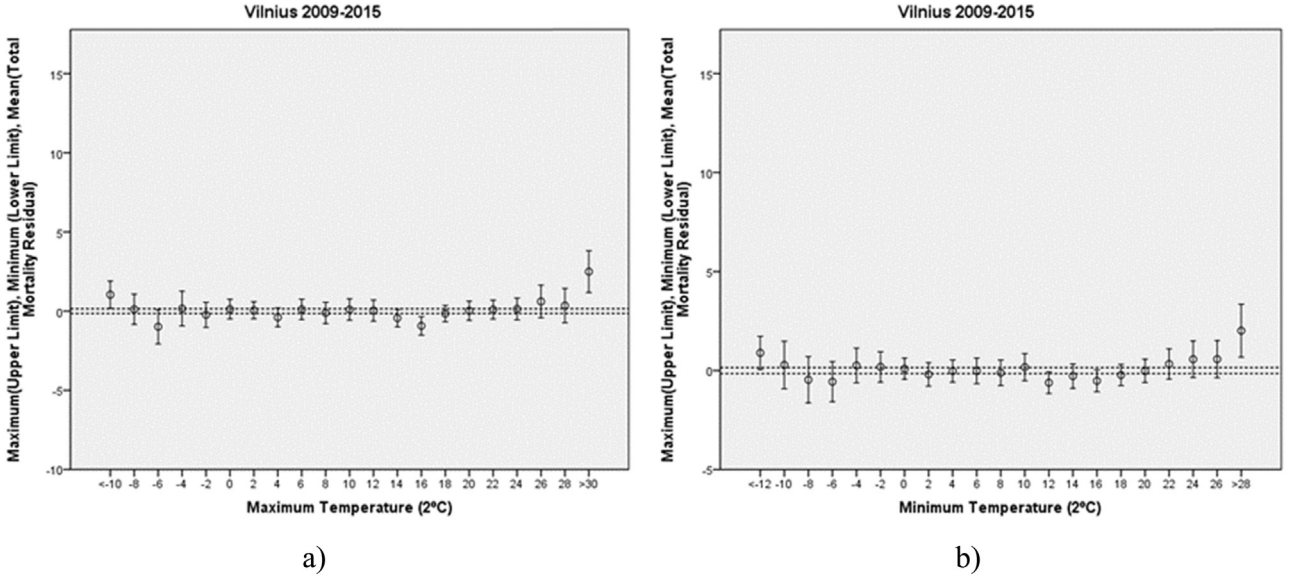

Fig. 1. Relationship between daily mortality and maximum daily temperature during the summer months (a) and relationship between mortality and minimum daily temperature during the winter months (b).

Table 2
Relative Risks (RR) and Population Attributable Fractions (PAF) for Theat (for each degree when Tmax exceeds 30 °C (June-September)) and for Tcold (for each degree when Tmin falls below −12 °C (November –March)), and for increases of 10 μg/m^3 in PM_{10}, $PM_{2.5}$ and SO_2 concentrations. Relative Humidity (RH).

Vilnius 2009–2015	Variable	RR (95%CI)	PAF (95%CI)
Total Mortality (June-September)	T_{heat} (lag 1)	1.076 (1.025–1.129)	7.1 (2.52–11.46)
	PM_{10} (lag 0)	1.027 (1.006–1.048)	2.6 (0.63–4.59)
Total Mortality (November-March)	T_{cold} (lag 1)	1.016 (1.003–1.029)	1.6 (0.29–2.81)
	$PM_{2.5}$ (lag 2)	1.017 (1.006–1.028)	1.7 (0.59–2.73)
	SO_2 (lag 1)	1.070 (1.016–1.127)	6.5 (1.57–11.26)
	RH (lag 2)	1.002 (1.000–1.003)	0.2 (0.01–0.39)

Table 3
Heat and cold attributable deaths during the sample period (2009–2015).

Vilnius (2009–2015)	Total Attributable Mortality (95%CI)	Annual Mortality
Tmax > 30 °C	52 (19–84)	7.4 (2.7–12)
Every day (N = 29days)	1.8(0.6–2.9)	
Tmin < −12 °C	70 (13–124)	10 (1.9–17.7)
Every day (N = 71 days)	1.0(0.2–1.7)	

persons (CI95% 135–614), with a mean heat-related mortality of 24 deaths per year (CI95%: 8–38). This value is 3.2 times that calculated for the sample period 2009–2015. In the "far future" period 2085–2100, the yearly number of "hot days" would increase further, to 20 a year. The total attributable mortality for the entire period would be 738 deaths (CI95% 262–1190), with a mean heat-related mortality of 46 deaths per year (CI95%: 16–74). On a yearly basis, this would represent an increase in attributable mortality by a factor of 6.2 compared with the sample period 2009–2015.

Under the second hypothesis, that is, a variable T_{max} threshold (i.e. a "hot day" is defined as one with Tmax > p96), there would be 77 "hot days" in Vilnius during the period 2030–2045 under RCP8.5, with 4.8 "hot days"/year versus the current figure of 4.1 days, a 20% increase respect 2009–2015. Attributable mortality across this entire period would be 162 persons (CI95% 57–261), with a mean heat-related mortality of 10 deaths per year (CI%: 4–17). This value is 1.4 times that calculated for the retrospective period 2009–2015. In the "far future" period 2085–2100, the yearly number of "hot days" would stay at 4.8, and the total attributable mortality for the entire period would be 96 deaths (CI95% 31–155). On a yearly basis, this would represent a decrease in attributable mortality by about 20% compared with the baseline period 2009–2015. These results are listed in Table 4, disaggregated by five-year periods.

3.2.2. Cold –related mortality for 2030–2045 and 2085–2100

On the basis of the fixed threshold under the first hypothesis (i.e. a "cold day" is defined as one in which minimum daily temperature drops below −12 °C), there would be 71 "cold days" in Vilnius during the period 2030–2045 under RCP8.5, with 4.4 "cold days"/year versus the current figure of 10.1 days, a 56% decrease. Attributable mortality across this entire period would be 72 persons (CI95% 13.13–127.21), with a mean cold related mortality of approximately 5 persons per year. This value is 54% lower than that calculated for the sample period 2009–2015.

In the "far future" period 2085–2100, the yearly number of "cold days" would decrease by 93%, and the total attributable mortality for the entire period would be 7 deaths (CI95% 1.25–12.13). On a yearly basis, this would represent a decrease in attributable mortality by 96% compared with the sample period 2009–2015.

Under the threshold definition for the second hypothesis (i.e. a "cold day" is defined as one with Tmin < percentile 7), there would be 167 "cold days" in Vilnius during the period 2030–2045 under RCP8.5, with 10.4 "cold days"/year versus the current figure of 10.1 days, that is, a negligible change. Attributable mortality across this entire period would be 200 persons (CI95% 37–352), with a mean cold-related mortality of 12.5 persons per year. This value is 1.3 times that calculated for the retrospective period 2009–2015. In the "far future" period 2085–2100, the yearly number of "cold days" would remain virtually unchanged at 10.6, and the total attributable mortality for the entire period would be 105 deaths (CI95% 19–184). On a yearly basis, this would represent a decrease in attributable mortality by about 35% compared with the baseline period 2009–2015. Results are shown in Table 5.

Table 4
Projected mortality attributable to hot days (i.e. with heat-related mortality) during the periods: 2030–2045 and 2085–2100, with reference to the established hypotheses.

Hypothesis 1: **Maximum daily temperature fixed at 30 °C constant**

Period	Days with heat-related mortality	Total Attributable Mortality	Daily Total Attributable Mortality	Total Attributable Mortality (every year)
2030–2034	42	94.69 (33.61–152.84)	2.25 (0.80–3.64)	18.94 (6.72–30.57)
2035–2039	29	70.82 (25.14–114.31)	2.44 (0.87–3.94)	14.16 (5.03–22.86)
2040–2045	71	215.11 (16.35–347.20)	3.03 (1.08–4.89)	35.85 (2.73–57.87)
2085–2089	109	224.70 (79.75–362.68)	2.06 (0.73–3.33)	44.94 (15.95–72.54)
2090–2094	83	164.88 (58.52–266.13)	1.99 (0.71–3.21)	32.98 (11.70–53.23)
2095–2100	128	347.95 (123.50–561.62)	2.72 (0.97–4.39)	57.99 (20.58–93.60)

Hypothesis 2: **Percentile 96 of maximum daily temperature fixed**

Period	Tmax Threshold (p96)	Days with heat-related mortality	Total Attributable Mortality	Daily Total Attributable Mortality	Total Attributable Mortality (every year)
2030–2034	30.90	24	57.32 (20.35–92.53)	2.39 (0.85–3.86)	11.46 (4.07–18.51)
2035–2039	30.20	24	63.33 (22.48–102.23)	2.64 (0.94–4.26)	12.67 (4.50–20.45)
2040–2045	32.80	29	41.09 (14.58–66.33)	1.42 (0.50–2.29)	6.85 (2.43–11.06)
2085–2089	33.49	24	31.04 (11.02–50.09)	1.29 (0.46–2.09)	6.21 (2.20–10.02)
2090–2094	32.87	24	36.29 (12.88–58.58)	1.51 (0.54–2.44)	7.26 (2.58–11.72)
2095–2100	35.25	29	28.53 (10.12–46.04)	0.98 (0.35–1.59)	4.76 (1.69–7.67)

4. Discussion

4.1. On heat and mortality in Vilnius, currently

The heat-related mortality threshold temperature, corresponding to a daily maximum of 30 °C (96th percentile of the maximum temperature series of the summer months), indicates that days with mortality attributable to heat are currently infrequent in Vilnius. This threshold temperature is in line with the climatic characteristics to which the Vilnius population is subjected (Curriero et al., 2002; Kovats et al., 2006) characterised by mild summers. However, several factors other than climate influence heat-related mortality, including the population pyramid, and the over-65 age group in particular (Díaz et al., 2002; Montero et al., 2012) as well as socio-economic factors, such as access to air conditioning, and the existence or absence of infrastructures adapted to heat (Abrahamson et al., 2008; Montero et al., 2012; Vandentorren et al., 2006). The fact that the association between high temperatures and mortality is established at lag 1 (an extremely short-term effect) is in line with the biological mechanisms implicated (Alberdi et al., 1998; Havenith, 2003; Díaz et al., 2015b). Quantitatively, the AR is higher than those of more temperate climates (e.g. Antwerp, see Martinez et al., 2018) and lower than those of southern Europe (e.g. Spain, see Díaz et al., 2015b).

4.2. On heat and mortality in Vilnius in the near and far future

Under a “no acclimatisation to heat” scenario, the current annual average figure of “hot day” would more than double in Vilnius by the period 2030–2045, and rise almost five-fold in the most distant time horizon 2085–2100. This increase in hot days is compatible with IPCC predictions (IPCC, 2013) which indicate that hot days will become increasingly frequent in Europe. In terms of health impacts, heat-related mortality would more than triple by 2030–2045, and increase more than 6-fold in 2085–2100 in relation to the current reference period.

The “no acclimatisation to heat” hypothesis may be taken as an upper limit, for a number of reasons. Demographic and socio-economic factors might account in part for the trend in minimum mortality temperatures (Miron et al., 2008). Studies conducted in different parts of the world conclude that the impact of heat on mortality is decreasing over time (Schifano et al., 2012), particularly in cardiovascular-cause mortality (Ha and Kim, 2013), while in the case of respiratory-cause mortality the effect remains practically constant (Miron et al., 2008). This trend seems to be linked to improvements in health services, socio-economic improvements, better built environments and a degree of acclimatisation of the population to heat (Konkel, 2014).

Modelling the heat-acclimatisation process as a rise in the hot day threshold temperature, by keeping the percentile of future temperature series constant, may serve as a benchmark to test whether adaptive

Table 5
Projected mortality attributable to cold days (i.e. with cold-related mortality)during the periods: 2030–2045 and 2085–2100, with reference to the established hypotheses.

Hypothesis 1: **Minimum daily temperature fixed at − 12 °C constant**

Period	Days with cold-related mortality	Total Attributable Mortality	Daily Total Attributable Mortality	Total Attributable Mortality (every year)
2030–2034	20	20.27 (3.70–35.84)	1.01 (0.18–1.79)	4.05 (0.74–7.17)
2035–2039	17	19.90 (3.60–34.94)	1.17 (0.21–2.06)	3.98 (0.72–6.99)
2040–2045	34	32.25 (5.85–56.63)	0.95 (0.17–1.66)	5.37 (0.98–9.43)
2085–2089	3	1.77 (0.32–3.11)	0.59 (0.10–1.04)	0.35 (0.06–0.62)
2090–2094	4	1.62 (0.29–2.85)	0.41 (0.07–0.71)	0.33 (0.06–0.57)
2095–2100	5	3.48 (0.63–6.11)	0.69 (0.12–1.22)	0.58 (0.10–1.02)

Hypothesis 2: **Percentile 7 of minimum daily temperature fixed**

Period	Tmin Threshold (p7)	Days with cold-related mortality	Total Attributable Mortality	Daily Total Attributable Mortality	Total Attributable Mortality (every year)
2030–2034	− 7.79	52	70.08 (12.70–123.07)	1.35 (0.24–2.37)	14.02 (2.54–24.62)
2035–2039	− 8.56	52	60.45 (10.96–106.17)	1.16 (0.21–2.04)	12.09 (2.19–21.22)
2040–2045	− 9.52	63	69.96 (12.67–122.86)	1.10 (0.20–1.95)	11.65 (2.11–20.48)
2085–2089	− 2.56	53	40.36 (7.31–70.89)	0.76 (0.14–1.33)	8.07 (1.46–14.18)
2090–2094	− 4.08	53	29.32 (5.34–51.72)	0.55 (0.10–0.98)	5.89 (1.07–10.35)
2095–2100	− 4.37	63	35.14 (6.37–61.71)	0.53 (0.10–0.98)	5.85 (1.06–10.29)

processes currently being implemented are adequate to the task. For instance, in order for heat-related mortality not to rise in Vilnius despite the increase in daily temperatures, the threshold temperature at the 2045 horizon should be 32.8 °C and 35.2 °C at 2100. Furthermore, it should also be borne in mind that annual mortality will gradually rise over time, something we have not taken into account, with the result that heat-related mortality, affected by this demographic factor, will increase accordingly.

4.3. On cold and health in Vilnius, currently

A systematic review conducted up to 2013 (Ryti *et al.* 2015) indicated that in most studies cold days were statistically defined on the basis of the frequency distribution of the set of days with extreme temperatures. The percentiles in those studies were between 1st and 3rd. The relatively high percentile value (7th percentile of the minimum temperatures of the winter months) in Vilnius may be related to cold acclimatisation factors and socio-economic conditions (Linares et al., 2016; Carmona et al., 2016). In general, cold-related mortality is associated with an increase in respiratory-cause mortality, though a relationship has been reported between low temperatures and circulatory-cause morbidity and mortality (Chau et al., 2014). Low temperatures are associated with a higher incidence of respiratory tract infections (Mäkinen et al., 2009), respiratory diseases (Monteiro et al., 2013), and excess mortality and morbidity due to cardiovascular diseases (Davídkovová et al., 2014). Multi-country global observational study found that moderate temperatures, rather than extreme temperatures, represented most of the total health burden (Gasparrini et al., 2015). The adverse health effects of cold temperatures are more pronounced in warmer climates (Ballester et al., 2011).

These results for Vilnius (significant at lag 1) suggest that most cold-related mortality is due to circulatory rather than respiratory causes. Cold-related mortality typically has a bimodal distribution, with a first peak of circulatory mortality between days 1–4 and a second peak in days 7–14 due to a higher degree to respiratory causes. This phenomenon is linked to the underlying biological mechanisms (Ryti et al., 2016). The AR obtained for this city in relation to cold is 1.6% for each degree that the minimum daily temperature falls below − 12 °C. According to a meta-analysis which addressed the impact of cold on mortality (Ryti et al., 2016), the AR of cold on all-cause mortality would be around 10% per degree, a value similar to that of circulatory causes (11%) and far higher than that of respiratory causes (20%). The low value found for Vilnius supports the notion that the population of Vilnius is well adapted to low temperatures. Residents of hot regions are known to show less physical, social and behavioural adaptation to low temperatures (Lin et al., 2013), with the effects of cold being more significant in such regions (Langford and Bentham, 1995; Wang et al., 2012) or in areas with moderate winter climates (Conlon et al., 2011).

The fact that daily mortality attributable to hot days is almost twice that due to cold, underscores the pressing need for the implementation of heat wave prevention plans in Vilnius. However, the data also clearly show a need for effective cold wave prevention plans in Vilnius, where the overall effect of cold on mortality is 20-fold that of heat (Gasparrini et al., 2015). Moreover, the recent trend of heat-related mortality is a decreasing one, whereas cold-related mortality is increasing (Díaz et al., 2015a).

4.4. On cold and health in Vilnius in the near and far future

"Cold days" would continue to occur under RCP8.5 in Vilnius, albeit falling to less than half the current number in the 2030–2045 and decreasing by over 90% by the end of the century, a finding in line with other studies (Kodra et al., 2011). Similarly, annual mortality attributable to cold is projected to fall, to a value around 2.5 times lower by 2030–2045 and by a factor of 20 in 2085–2100 in relation to the current values. This decline in cold-related mortality is also in line with the results reported by other studies (Gasparrini et al., 2015). Mortality estimates obtained until the year 2050 with 20 climate models in 209 cities of the USA (Wang et al., 2016) suggest that future mortality associated with cold days and prolonged cold waves (i.e., those occurring less than seven days after the end of the preceding one) will decline over time by 0% to − 2.1%, values close to those obtained in another study (1.59%) undertaken in the USA (Medina-Ramón and Schwartz, 2007). Yet, other studies based on a meta-analysis (Ryti et al., 2016) performed until February 2013, which included studies from China, The Netherlands and Yakutsk, reported rises in mortality of the order of 10%.

4.5. Will the decrease in cold-related mortality compensate the increase in heat-related mortality?

In the case of heat, with a constant threshold there is a strong increase in heat-related mortality, due to the increase in the number of hot day episodes. However, if we assume a process of acclimatisation (the temperature series percentile remains constant but as climate warms that percentile corresponds to higher temperatures), heat-related mortality increases until the year 2035 and decreases thereafter due to the evolution in the mortality rate. Evidently, such a sharp rate of acclimatisation is unlikely, but some degree of heat acclimatisation is clearly happening (Gasparrini et al., 2015; Miron et al., 2015; Díaz et al., 2015a; Ha and Kim, 2013; Petkova et al., 2014). Therefore, we may assume that expected mortality by the year 2100 may be somewhere between both hypotheses. How close to one or the other will depend on the impact of the adaptation processes, whether natural or institutionally driven.

The steep decrease in cold-related mortality is caused by the combination of a constant threshold definition and a reduction in the number of cold days under a warming climate. Put simply, less cold episodes would qualify as "cold days" under that assumption. However, if such threshold temperature increases (i.e. populations become used

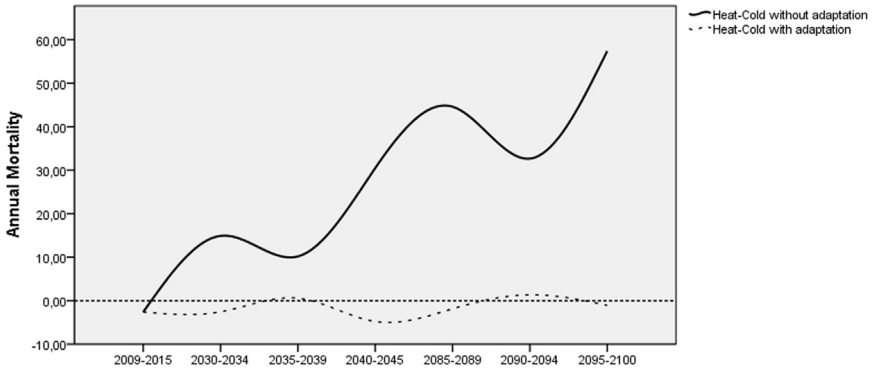

Fig. 2. Time trend of the annual mortality attributable to heat and cold, according the different periods and hypothesis.

to less cold) and the number of cold days remains practically constant in time, the mortality reduction would be less pronounced, as can be seen in Fig. 2. In addition, since we have assumed the cold and heat AR to be constant, we have not captured a possible increase of the impact of cold on daily mortality (Díaz et al., 2015a; Gasparrini et al., 2015).

Overall, if we assume no acclimatisation for either heat or cold, the increase in heat-related mortality would clearly outweigh reductions in cold-related mortality. Fig. 2 shows the yearly evolution of the difference between heat-related and cold-related mortality (i.e. yearly heat-related mortality minus yearly cold-related mortality), assuming either a constant threshold definition temperature, or a changing one.

If we assume that future cold-attributable mortality may be somewhere between both scenarios, the decrease in cold day mortality (due to fewer cold days) will generally not compensate the increase in hot day mortality (due to more hot days) (Staddon et al., 2014). Thus, the benefits of a warmer climate may be quite limited from the standpoint of direct effects of temperature on mortality (Kinney et al., 2015)

4.6. Limitations and biases

Several limitations of this study should be mentioned: firstly, with reference to the quality and consistency of the data analysed, 3-hourly daytime temperatures were used as proxies for daily maximum and daily minimum temperature. Regarding the minimum daily temperature used to define cold days, it is worth noting that sunrise in the middle of our wintertime period (i.e. December 31st) happens at 8:39 A.M. (Sunrisesunset, 2018). Since minimum daily temperatures are typically reached one hour after sunrise, using 9 A.M. measurements is not a far-off proxy. Similarly, sunrise in Vilnius on 21 June happens at 04:39 A.M., so that by noon, the sun has had about 7 and a half hours to increase temperatures (Sunrisesunset, 2018). Climatological series indicate an average of daily maximum temperatures for Vilnius of 10.46 °C (Climate, data, 2018), a very close value to the one in this study, of 0.08 °C. Furthermore, using measurements at 12 h as maximum daily temperature (in the absence of complete hourly series) seems justifiable in this case since the average 12 h temperature series was higher than that of the 15 h temperature series.

Another possible limitation of this study is the potential misclassification of the cause of mortality. However, since we only considered natural causes excluding accidental deaths and suicides, the potential for this type of bias is limited. In relation to the lack of data on environmental variables, and pollution in particular and meteorology to a lesser extent, led to the use of statistical methods to fill the gaps, with the resulting errors.

With respect to methodological limitations, essentially two should be highlighted: 1) the shortcomings inherent in a statistical method that works with a high number of variables at a 95% confidence level; and 2) this is an ecological study, which means that inferences cannot be made at an individual level. It is only possible to show the existence of a statistical association between the variables analysed. Factors favouring the existence of a real -as opposed to a spurious- relationship, are the high correlation index, increasing dose-response relationship, absence of temporal ambiguity, biological plausibility of the effect shown in clinical studies, and consistency of results obtained by previous studies.

Furthermore, in the case of estimates of the impact of temperatures on mortality, various hypotheses were postulated, including the assumption of mortality being constant over time, the related population attributable fraction remaining similarly constant, as well as the mortality threshold temperature associated with the extreme temperatures. Although these aspects have been addressed in the Discussion section, it is evident that their use might lead to biases in the results obtained in this study.

4.7. Implications for prevention

Cold-related mortality in Vilnius is, unsurprisingly, currently a greater public health problem than heat-related mortality in absolute terms; it is more than twice as frequent, and more people are killed by cold on a yearly basis than by heat. However, daily heat-related mortality in Vilnius currently practically doubles that attributable to cold. Moreover, heat is set to become a greater public health problem in Vilnius due to climate change and demographics. That suggests a high vulnerability and points to an urgent need to design and implement adequate measures within a coherent heat-health action plan. Those measures need to take into account this changing landscape, and be calibrated on the existing epidemiological evidence (E.g. the very short lag time between high temperatures and mortality). In the case of Lithuania, institutional efforts are currently underway to address these public health factors (in fact, this study was partly intended to support such efforts in terms of evidence base). Given these results, implementation should be urgent, and incorporate climate change considerations from the inception, making an explicit link with adaptation activities, both general and specific to the health sector, and on a multilevel governance framework with clear roles also for authorities at the local level.

5. Conclusions

Thermal extremes, both heat and cold, constitute a serious public health threat in Vilnius. Cold causes currently more premature deaths than heat in Vilnius, and effective public health preventive action is needed locally in cold-health prevention. However, efforts in heat-health prevention are also warranted in this case. High temperatures are comparatively deadlier in an unacclimatised population, and they are set to become more extreme and more frequent under climate change. Moreover, the decrease in mortality attributable to cold will not compensate for the increase in mortality attributable to heat in Vilnius. Our results reinforce the notion that public health prevention against thermal extremes should be understood as a dynamic, adaptive process from the inception.

Acknowledgements

This paper reflects the authors' views. Neither the European Commission nor the World Health Organization, ISCIII, UNEP-DTU partnership, Centre for Health Education and Diseases or the VITO are liable for any use that may be made of the information contained therein. We gratefully acknowledge the contributions of Dr Judita Liukaityte (Lithuanian Hydrometeorological Services), Dr Justas Kazys (Vilnius University), the support of Dr Ingrida Zurlyte (WHO Country Office in Lithuania), Dr Romualdas Sabaliauskas (Centre for Health Education and Diseases Prevention) and the collaboration and inputs from the local and national authorities in Vilnius. The authors gratefully acknowledge the Project ENPY 1133/16 and Project ENPY 107/18 grant from the Carlos III Institute of Health.

DeclarationsEthics approval and consent to participate

Not applicableConsent for publication

Not applicable.Competing interests

The authors have no competing interests, financial or otherwise.Funding

The research leading to these results has received funding from the European Community's Seventh Framework Programme under Grant Agreement No. 308497 (Project RAMSES). The funding body (European Commission) did not play any role in the design of the study and collection, analysis, interpretation of data or in writing the manuscript.Authors' contributions

GSM designed and coordinated the study, and drafted this article; JD coordinated and supervised the epidemiological analysis, which was carried out by CL, RC and CO. HH and DL collaboratively carried out the urban climate and climate change modelling, with the supervision

and collaboration of KDR. VK provided inputs and context for the discussion and introduction sections. DA collected and analysed population data, formatted the draft and references, and managed the peer review coordination among authors.Authors' information

Not applicable.Endnotes

Not applicable.

References

Abrahamson, V., Wolf, J., Lorenzoni, I., Fenn, B., Kovats, S., Wilkinson, P., et al., 2008. Perceptions of heatwave risks to health: interview-based study of older people in London and Norwich, UK. J. Public Health 31 (1), 119–126.

Alberdi, J.C., Díaz, J., Montero, J.C., Mirón, I., 1998. Daily mortality in Madrid community 1986–1992: relationship with meteorological variables. Eur. J. Epidemiol. 14 (6), 571–578.

Anderson, B.G., Bell, M.L., 2009. Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. Epidemiology (Cambridge, Mass.) 20 (2), 205–213.

Ballester, J., Robine, J.M., Herrmann, F.R., Rodó, X., 2011. Long-term projections and acclimatization scenarios of temperature-related mortality in Europe. Nat. Commun. 2, 358.

Box, G.E.P., Jenkins, G.M., Reinsel, G.C., 1994. Time Series Analysis, Forecasting and Control, third ed. Prentice Hall, Englewood.

Carmona, R., Diaz, J., Miron, I.J., Ortiz, C., Leon, I., Linares, C., 2016. Geographical variation in relative risks associated with cold waves in Spain: the need for a cold wave prevention plan. Environ. Int. 88, 103–111.

Chau, P.H., Wong, M., Woo, J., 2014. Ischemic heart disease hospitalization among older people in a subtropical City—Hong Kong: Does winter have a greater impact than summer? Int. J. Environ. Res. Public Health 11 (4), 3845–3858.

Climate – data, 2018. Climate data: Vilnius. 〈https://es.climate-data.org/location/431/〉 (accessed 7 February 2018).

Cohen, J., Screen, J.A., Furtado, J.C., Barlow, M., Whittleston, D., Coumou, D., et al., 2014. Recent Arctic amplification and extreme mid-latitude weather. Nat. Geosci. 7 (9), 627–637.

Conlon, K.C., Rajkovich, N.B., White-Newsome, J.L., Larsen, L., O'Neill, M.S., 2011. Preventing cold-related morbidity and mortality in a changing climate. Maturitas 69 (3), 197–202.

Curriero, F.C., Heiner, K.S., Samet, J.M., Zeger, S.L., Strug, L., Patz, J.A., 2002. Temperature and mortality in 11 cities of the eastern United States. Am. J. Epidemiol. 155 (1), 80–87.

Davídkovová, H., Plavcová, E., Kynčl, J., Kyselý, J., 2014. Impacts of hot and cold spells differ for acute and chronic ischaemic heart diseases. BMC Public Health 14 (1), 480.

Díaz, J., García, R., Ribera, P., Alberdi, J.C., Hernández, E., Pajares, M.S., Otero, A., 1999. Modeling of air pollution and its relationship with mortality and morbidity in Madrid, Spain. Int. Arch. Occup. Environ. Health 72 (6), 366–376.

Díaz, J., Jordan, A., García, R., López, C., Alberdi, J., Hernández, E., Otero, A., 2002. Heat waves in Madrid 1986–1997: effects on the health of the elderly. Int. Arch. Occup. Environ. Health 75 (3), 163–170.

Díaz, J., García, R., Lopez, C., Linares, C., Tobías, A., Prieto, L., 2005. Mortality impact of extreme winter temperatures. Int. J. Biometeorol. 49 (3), 179–183.

Díaz, J., García-Herrera, R., Trigo, R.M., Linares, C., Valente, M.A., De Miguel, J.M., Hernández, E., 2006. The impact of the summer2003 heat wave in Iberia: how should we measure it? Int. J. Biometeorol. 50 (3), 159–166.

Díaz, J., Carmona, R., Mirón, I.J., Ortiz, C., Linares, C., 2015a. Comparison of the effects of extreme temperatures on daily mortality in Madrid (Spain), by age group: the need for a cold wave prevention plan. Environ. Res. 143, 186–191.

Díaz, J., Carmona, R., Mirón, I.J., Ortiz, C., León, I., Linares, C., 2015b. Geographical variation in relative risks associated with heat: update of Spain's Heat Wave Prevention Plan. Environ. Int. 85, 273–283.

DoS, 2018. Population statistics of the Republic of Lithuania. Retrieved from 〈https://osp.stat.gov.lt/pradinis〉.

Gasparrini, A., et al., 2017. Projections of temperature-related excess mortality under climate change scenarios. Lancet Planet Health 1 (9), e360–e367. http://dx.doi.org/10.1016/S2542-5196(17)30156-0.

Gasparrini, A., Guo, Y., Hashizume, M., Lavigne, E., Zanobetti, A., Schwartz, J., et al., 2015. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet 386 (9991), 369–375.

Guo, Y., et al., 2017. Heat wave and mortality: a multicountry, multicommunity study (Aug 10). Environ. Health Perspect. 125 (8), 087006. http://dx.doi.org/10.1289/EHP1026.

Ha, J., Kim, H., 2013. Changes in the association between summer temperature and mortality in Seoul, South Korea. Int. J. Biometeorol. 57 (4), 535–544.

Havenith, G., 2003. Clothing and thermoregulation. Curr. Probl. Dermatol. 31, 35–49.

IPCC, 2013. Climate Change. The Physical Science Basis. Working Group I. Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Jiménez, E., Linares, C., Rodríguez, L.F., Bleda, M.J., Díaz, J., 2009. Short-term impact of particulate matter (PM2. 5) on daily mortality among the over-75 age group in Madrid (Spain). Sci. Total Environ. 407 (21), 5486–5492.

Kinney, P.L., Schwartz, J., Pascal, M., Petkova, E., Le Tertre, A., Medina, S., Vautard, R., 2015. Winter season mortality: will climate warming bring benefits? Environ. Res. Lett. 10 (6), 064016.

Kodra, E., Steinhaeuser, K., Ganguly, A.R., 2011. Persisting cold extremes under 21st-century warming scenarios. Geophys. Res. Lett. 38 (8).

Konkel, L., 2014. Learning to take the heat: declines in US heat-related mortality. Environ. Health Perspect. 122 (8), A220.

Kovats, R.S., Johnson, H., Griffith, C., 2006. Mortality in southern England during the 2003 heat wave by place of death. Health Stat. Q 29 (3), 6–8.

Langford, I.H., Bentham, G., 1995. The potential effects of climate change on winter mortality in England and Wales. Int. J. Biometeorol. 38 (3), 141–147.

Lin, Y.K., Wang, Y.C., Lin, P.L., Li, M.H., Ho, T.J., 2013. Relationships between cold-temperature indices and all causes and cardiopulmonary morbidity and mortality in a subtropical island. Sci. Total Environ. 461, 627–635.

Linares, C., Díaz, J., Tobías, A., Miguel, J.D., Otero, A., 2006. Impact of urban air pollutants and noise levels over daily hospital admissions in children in Madrid: a time series analysis. Int. Arch. Occup. Environ. Health 79 (2), 143–152.

Linares, C., Mirón, I.J., Carmona, R., Sánchez, R., Díaz, J., 2016. Time trend in natural-cause, circulatory-cause and respiratory-cause mortality associated with cold waves in Spain, 1975–2008. Stoch. Environ. Res. Risk Assess. 30 (6), 1565–1574.

Liukaitytė, J., 2011. Quantitave Evaluation of Biometeorological Conditions in Lithuania (Doctoral dissertation, Vilnius University). Vilnius University Press, Vilnius (133 p).

Mäkinen, T.M., Juvonen, R., Jokelainen, J., Harju, T.H., Peitso, A., Bloigu, A., Silvennoinen-Kassinen, S., Leinonen, M., Hassi, J., 2009. Cold temperature and low humidity are associated with increased occurrence of respiratory tract infections. Respir. Med. Mar. 103 (3), 456–462.

Martinez, G.S., Baccini, M., De Ridder, K., Hooyberghs, H., Lefebvre, W., Kendrovski, V., et al., 2016. Projected heat-related mortality under climate change in the metropolitan area of Skopje. BMC Public Health 16 (1), 407.

Martinez, G.S., Diaz, J., Hooyberghs, H., Lauwaet, D., De Ridder, K., Linares, C., et al., 2018. Heat and health in Antwerp under climate change: projected impacts and implications for prevention. Environ. Int. 111, 135–143.

Medina-Ramón, M., Schwartz, J., 2007. Temperature, temperature extremes, and mortality: a study of acclimatisation and effect modification in 50 US cities. Occup. Environ. Med. 64 (12), 827–833.

Melillo, J.M., 2014. Climate Change Impacts in the United States: the Third National Climate Assessment. Government Printing Office.

Miron, I.J., Criado-Alvarez, J.J., Diaz, J., Linares, C., Mayoral, S., Montero, J.C., 2008. Time trends in minimum mortality temperatures in Castile-La Mancha (Central Spain): 1975–2003. Int. J. Biometeorol. 52 (4), 291–299.

Miron, I.J., Linares, C., Montero, J.C., Criado-Alvarez, J.J., Díaz, J., 2015. Changes in cause-specific mortality during heat waves in central Spain, 1975–2008. Int. J. Biometeorol. 59 (9), 1213–1222.

Monteiro, A., Carvalho, V., Góis, J., Sousa, C., 2013. Use of "Cold Spell" indices to quantify excess chronic obstructive pulmonary disease (COPD) morbidity during winter (November to March 2000–2007): case study in Porto. Int. J. Biometeorol. 57 (6), 857–870.

Montero, J.C., Mirón, I.J., Criado-Álvarez, J.J., Linares, C., Díaz, J., 2012. Influence of local factors in the relationship between mortality and heat waves: castile-la Mancha (1975–2003). Sci. Total Environ. 414, 73–80.

Peng, R.D., Bobb, J.F., Tebaldi, C., McDaniel, L., Bell, M.L., Dominici, F., 2011. Toward a quantitative estimate of future heat wave mortality under global climate change. Environ. Health Perspect. 119 (5), 701–706.

Petkova, E.P., Gasparrini, A., Kinney, P.L., 2014. Heat and mortality in New York City since the beginning of the 20th century. Epidemiology (Cambridge, Mass.) 25 (4), 554–560.

Rocklov, J., Forsberg, B., Ebi, K., Bellander, T., 2014. Susceptibility to mortality related to temperature and heat and cold wave duration in the population of Stockholm County, Sweden. Glob. Health Action 7 (1), 22737.

Roldán, E., Gómez, M., Pino, M.R., Pórtoles, J., Linares, C., Díaz, J., 2016. The effect of climate-change-related heat waves on mortality in Spain: uncertainties in health on a local scale. Stoch. Environ. Res. Risk Assess. 30 (3), 831–839.

Ryti, N.R., Guo, Y., Jaakkola, J.J., 2016. Global association of cold spells and adverse health effects: a systematic review and meta-analysis. Environ. Health Perspect. 124 (1), 12–22.

Schifano, P., Leone, M., De Sario, M., de'Donato, F., Bargagli, A.M., D'Ippoliti, D., et al., 2012. Changes in the effects of heat on mortality among the elderly from 1998–2010: results from a multicenter time series study in Italy. Environ. Health 11 (1), 58.

Staddon, P.L., Montgomery, H.E., Depledge, M.H., 2014. Climate warming will not decrease winter mortality. Nat. Clim. Change 4 (3), 190–194.

Stafoggia, M., Schwartz, J., Forastiere, F., Perucci, C.A., 2008. Does temperature modify the association between air pollution and mortality? A multicity case-crossover analysis in Italy. Am. J. Epidemiol. 167 (12), 1476–1485.

Stieb, D.M., Szyszkowicz, M., Rowe, B.H., Leech, J.A., 2009. Air pollution and emergency department visits for cardiac and respiratory conditions: a multi-city time-series analysis. Environ. Health 8 (1), 25.

Styra, D., Usovaite, A., Damauskaite, J., Juozulynas, A., 2009. Leaps in cardiovascular diseases after a decrease of hard cosmic ray flux and atmospheric pressure in Vilnius city in 2004–2007. Int. J. Biometeorol. 53 (6), 471–477.

Sunrisesunset, 2018. 〈http://sunrisesunset.info/ciudades-letonia/salida-puesta-sol-vilnius/〉 (Accessed 7 February 2018).

UNDESA, 2008. Assumptions underlying the results of the 2006 revision of World Population Prospects. Population division of the department of economic and social affairs of the United Nations Secretariat, New York.

UNDESA, 2013. World population prospects: the 2012 revision. Population division of the department of economic and social affairs of the United Nations Secretariat, New York.

Vaičiulis, V., Radišauskas, R., 2014. The impact of seasonal and meteorological factors changes on morbidity and mortality from acute myocardial infarction in 2000–2010 years. Public Health 2 (65), 74–80.

Vandentorren, S., Bretin, P., Zeghnoun, A., Mandereau-Bruno, L., Croisier, A., Cochet, C.,

et al., 2006. August 2003 heat wave in France: risk factors for death of elderly people living at home. Eur. J. Public Health 16 (6), 583–591.
Wang, Y., Shi, L., Zanobetti, A., Schwartz, J.D., 2016. Estimating and projecting the effect of cold waves on mortality in 209 US cities. Environ. Int. 94, 141–149.
Wang, Y.C., Lin, Y.K., Chuang, C.Y., Li, M.H., Chou, C.H., Liao, C.H., Sung, F.C., 2012. Associating emergency room visits with first and prolonged extreme temperature event in Taiwan: a population-based cohort study. Sci. Total Environ. 416, 97–104.
Wu, J., Zhou, Y., Gao, Y., Fu, J.S., Johnson, B.A., Huang, C., et al., 2014. Estimation and uncertainty analysis of impacts of future heat waves on mortality in the eastern United States. Environ. Health Perspect. 122 (1), 10–16.
Zhang, J., Tian, W., Chipperfield, M.P., Xie, F., Huang, J., 2016. Persistent shift of the Arctic polar vortex towards the Eurasian continent in recent decades. Nat. Clim. Change 6 (12), 1094–1099.
Zmirou, D., Schwartz, J., Saez, M., Zanobetti, A., Wojtyniak, B., Touloumi, G., et al., 1998. Time-series analysis of air pollution and cause-specific mortality. Epidemiology 495–503.